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COLLECTION OF SUSPENDED PARTICULATES WITH SEDIMENT TRAPS IN THE TORONTO WATERFRONT

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ABSTRACT

A sediment trap study was undertaken in the nearshore zone of the Toronto Waterfront during 1983 and 1984 to assess the applicability of the method and to provide chemistry data on suspended particulates. Results from cylindrical settling tubes installed 1 m from the bed showed order of magnitude differences in suspended particulate fluxes between input stations (a lakefilling operation and a sewage treatment plant) and background stations. These differences were attributable chiefly to localized inputs of suspended particulates, particularly during the summer months when resuspension due to wave action was at a minimum. A progressive increase in particulate fluxes was detected through the fall and winter at all unsheltered stations consistent with expected increased shoreline erosion and resuspension of material deposited during the summer. Background fluxes ranged from approximately 10 $g.m^{-2}\ d^{-1}$ to 200 $g.m^{-2}\ d^{-1}$, while fluxes near the Toronto Main Sewage Treatment Plant varied from 42 $g.m.^{-2}\ d^{-1}$ to 1,026 $g.m.^{-2}\ d^{-1}$. The increase in fluxes of coarser material over the winter decreased bulk chemistry concentrations. Although stations could not be distinguished through single parameter comparison of grain size or chemistry results, the potential for distinction on the basis of linear correlations between parameters was identified. The study demonstrated the need for application of sediment traps in investigations into sediment transport as well as identification of suspended particulate sources.

ADDITIONAL INDEX WORDS: Sediment fluxes, sediment chemistry.

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1. INTRODUCTION

Investigations into the fate of contaminants such as heavy metals and trace organics in the aquatic environment have identified the need for an improved understanding of particulate transport in nearshore areas of the Great Lakes. The association between sediment particles and contaminants (Forstner and Wittman 1981) suggests that evaluation of surface water quality alone may not adequately describe the nearshore impact of inputs such as rivers, lakefilling projects, or sewage treatment plant (STP) discharges.

During the past few years researchers have used sediment traps to estimate sedimentation rates in Lake Ontario at depths ranging from 20 m to 130 m as well as to examine certain aspects of sediment chemistry (Charlton 1983, Rosa 1985). Estimates of the downflux contribution attributable to resuspension of previously deposited bed sediments have been featured in these investigations since absolute sedimentation rates can only be inferred directly from sediment trap studies under quiescent, non-turbulent conditions (Blonquist and Hakanson 1981). The extreme nearshore environment has generally been considered unsuitable for sediment trap investigations due to the relatively energetic conditions which may be encountered.

The present study was designed to assess the use of sediment traps under these conditions in order to determine their most appropriate application for future studies by:

(a) testing their performance across the eastern Toronto Waterfront in depths of less than 20 m, and

(b) obtaining chemistry data for suspended particulates and providing an interpretation of their significance.

2. STUDY SITE

The eastern Toronto Waterfront area of the Lake Ontario nearshore zone provides a useful study site for sediment trap evaluation since a range of depositional environments and several sources of suspended particulates are encountered shoreward of the 20 m depth contour (which delineates the Toronto shelf) within a range of less than 15 km (Figure 1). Between the Toronto Island and R.C. Harris Filtration Plant intakes (Figure 1) sediments with adsorbed contaminants may be discharged from the Don River and the Toronto Main STP, as well as from lakefilling at the East Headland. In general, the area is exposed to waves from the NE through SW, although the construction of the East Headland has provided localized protection from easterly waves. This area is also of interest in that recent studies have identified elevated contaminant levels in both bed sediments (Persaud et al. 1985) and suspended sediments (Boyd and Griffiths 1985).

3. THEORETICAL ASSUMPTIONS

Sandilands and Mudroch (1983), and Charlton (1983) have noted the existence of a nepheloid layer (i.e. a zone of increased turbidity near the bed) in Lake Ontario in depths of more than 60 m. Nearshore investigations have demonstrated that under certain conditions similar turbidity profiles can be observed in depths of less than 20 m (Boyd and Griffiths 1985). Although the physical processes responsible for these observations may differ between offshore and nearshore locations, in both cases it is evident that concentrations of suspended particulates and associated contaminants are greater near the bed than near the surface.

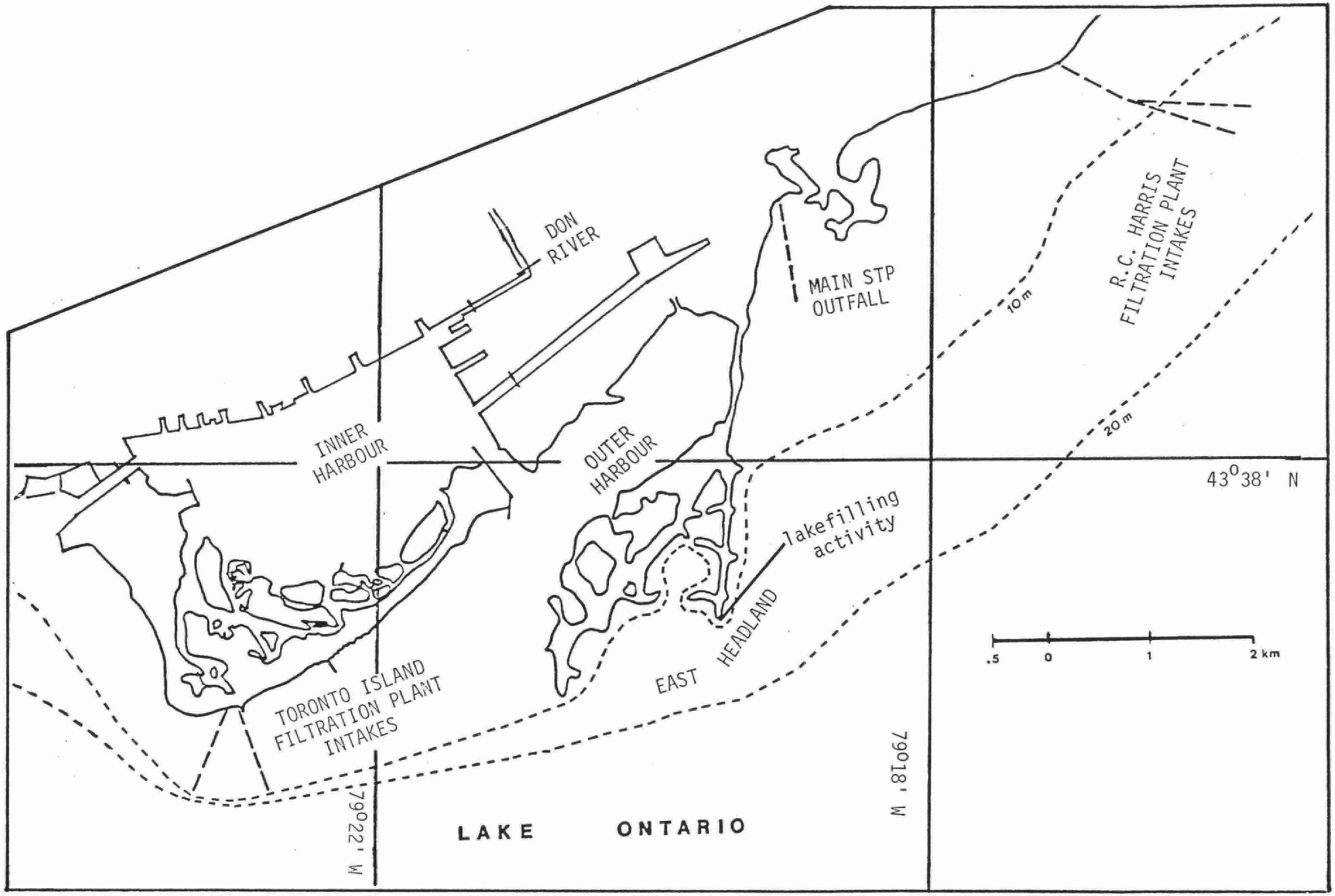


FIGURE 1: The Eastern Toronto Waterfront Area of the Lake Ontario Nearshore Zone

In the case of the nearshore environment, the most probable reasons for encountering an increasing turbidity gradient with depth are: (a) resuspension of bed sediments by surface gravity waves and mean currents, and (b) incomplete settling of transient surface inputs. Since much of the nearshore region of the Toronto Waterfront is a non-depositional zone in which bed sediments contain large percentages of sand (Lewis and Sly 1971, Persaud et al. 1985), it is evident that transport, or resuspension and transport, of silts and clays is a relatively continuous process. It is also apparent that in these relatively shallow depths the local energy environment responsible for the entrainment and suspension of particulates will be dominated by surface waves since the boundary shear stress associated with the oscillatory currents under a wave may be an order of magnitude larger than the shear stress associated with a unidirectional current of the same velocity (Grant and Madsen 1979).

For these reasons it can be assumed that resuspension by surface waves and subsequent transport by mean flows (either longshore or offshore) are responsible for the predominantly sandy substrate encountered throughout the study area, and that these processes do not preclude the existence of an increasing turbidity gradient with depth (although other profile conditions would also be possible). It will also be assumed that the concentration of suspended particulates at a given distance from the bed represents a dynamic equilibrium of upfluxes and downfluxes so that measurement of downfluxes at a particular depth (i.e. collection of material in a trap) can be considered proportional to the total suspended particulate concentration at that depth.

These assumptions result in theoretical limitations on any attempt to use sediment traps in the energetic nearshore environment. First, the orbital velocity and bed shear stress under a given deep water wave will increase with decreasing depth and, consequently, sediment traps located near the bed in shallow water may be expected to accumulate a relatively larger proportion of resuspended material than those located in deep water. Second, the presence of this shore-normal gradient in bed shear stress will also tend to reduce the trapping efficiency of traps located in shallow water due to resuspension losses from the traps themselves.

Provided traps are constructed so as to minimize resuspension losses under the most energetic conditions anticipated (i.e. trapping efficiencies can be assumed constant), a comparison of relative differences in downflux rates can be made between locations which will reflect their exposure to differing concentrations of suspended particulates over the collection period. Accumulation rates measured in nearshore sediment traps should, therefore, be considered representative of relative suspended particulate fluxes, not actual sedimentation rates. Differences in observed fluxes can then be attributed to a combination of differing energy environments and proximity to suspended particulate sources such as lakefilling operations or STP discharges.

4. MATERIALS AND METHODS

4.1 Trap Construction and Installation

The trap design was based on a review of work by Blonquist and Hakanson (1981). A cylindrical design was favoured, since bottle and funnel shapes have been shown to overtrap and undertrap respectively, and an inner diameter of 10 cm was required to ensure that over representation of the organic fraction did not occur. A height to diameter ratio of 4:1 was chosen to minimize resuspension losses.

The collection tubes were constructed from ABS plastic pipe to reduce breakages and to eliminate sample contamination by metals. The collection tubes were closed at one end with an ABS end cap fastened with ABS solvent cement, while the open end was capped under water during retrieval with a standard ABS fitting (Figure 2). One large diameter (20 cm) trap was also constructed to investigate the effects of diameter (the 4:1 height to diameter ratio was maintained for the large trap) on trapping efficiency and chemistry.

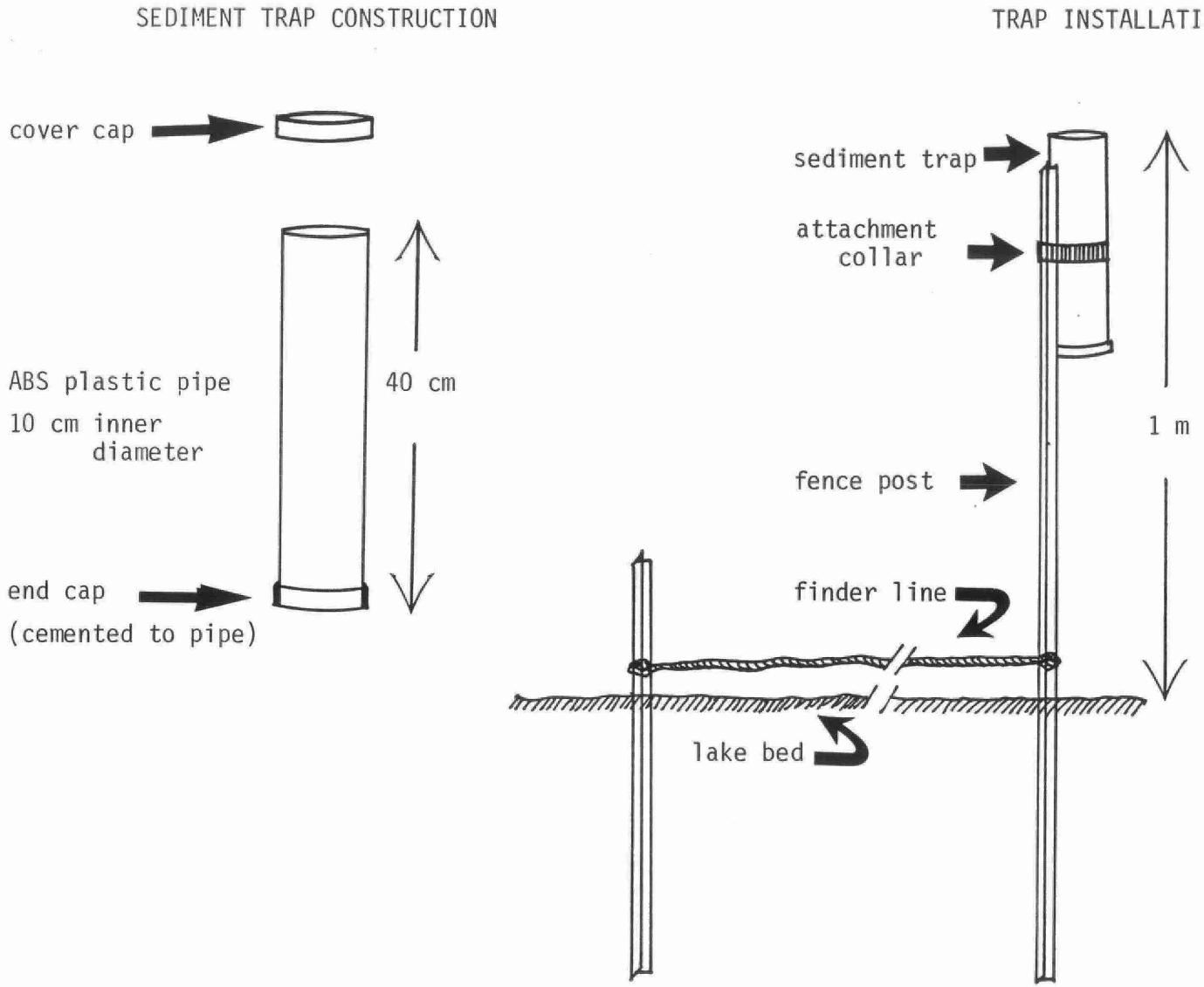
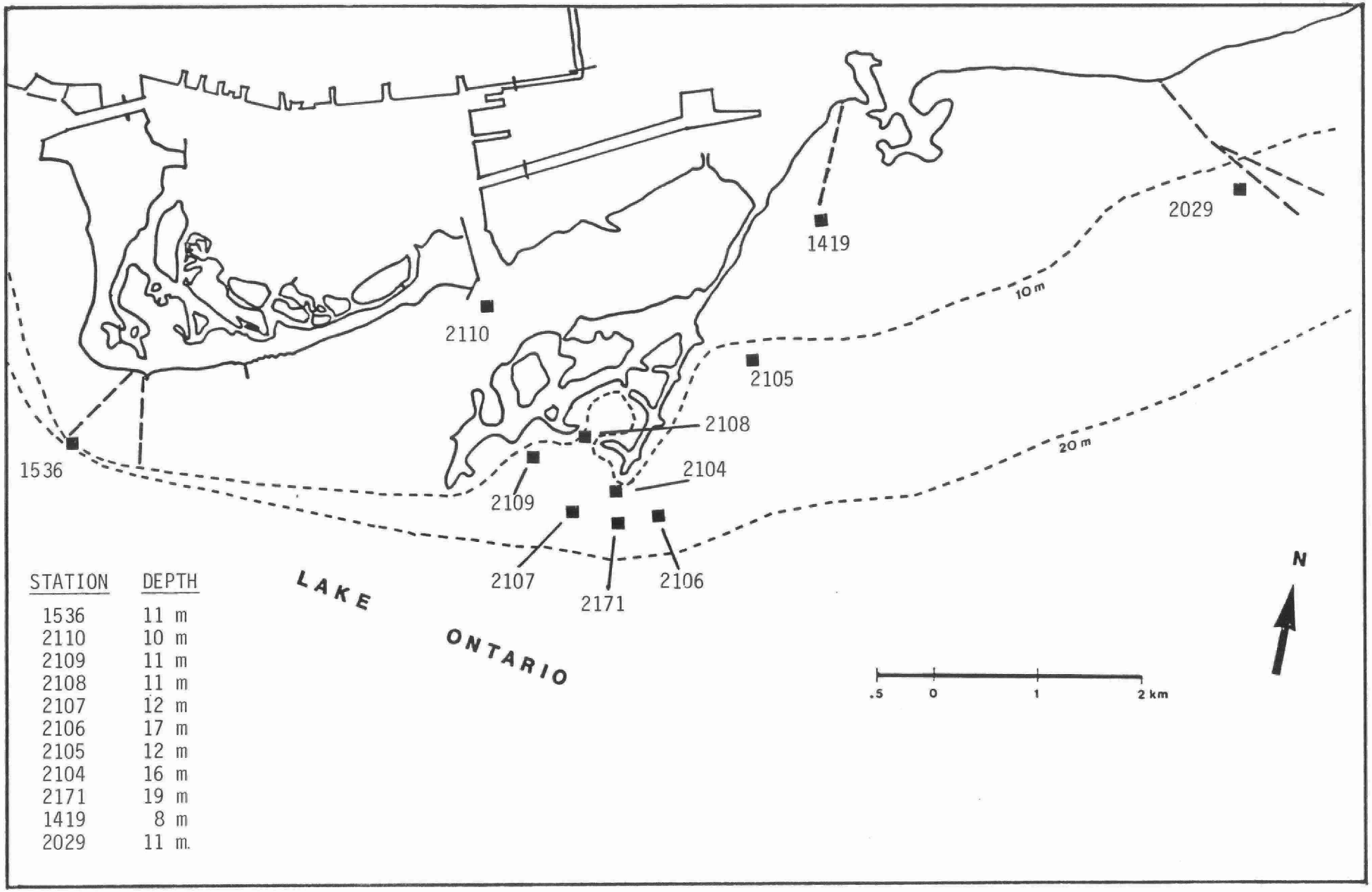


FIGURE 2: 1983/84 Toronto Waterfront Sediment Trap Design and Installation Arrangement

A preliminary reconnaisance was undertaken during the period June 11 - 16, 1983 to establish the most advantageous locations for trap deployment. Results of an echo sounding survey and diver inspection (Limnos 1984) showed evidence of both sedimentation and wave action. The lake bed immediately to the east of the East Headland (Figure 1) consisted predominantly of sand overlain with a 1-2 cm layer of silt which decreased in thickness away from shore. Sandbars and bed ripples parallel to the shoreline (indicative of wave action) were observed, and small pockets of organic material were found within the troughs along the whole eastern face of the East Headland. At the southeastern tip of the East Headland superimposed ripples were observed indicating several directions of wave approach. While only a limited surface turbidity plume was evident at the site of active lakefilling during the diver reconnaissance, a substantial subsurface turbidity plume was encountered.

Traps were installed by divers at 11 locations across the study area: seven of them in depths of 10-12 m, three in depths of 16-19 m, and one in 8 m (Figure 3). These locations covered various combinations of energy environments and proximity to sources of suspended particulates. The traps were clamped to a 2 m length of steel fence post which was driven into the lake bed with a post driver. The collection tubes were fastened so that the open end of the tube was 1 m from the lake bed with the nylon attachment ring (clamp) located away from the mouth of the tube to minimize turbulence. This rigid anchorage system 1 m above the bed was designed to ensure that the collection tubes remained stationary and vertical (since any movement out of the vertical position would reduce the effective trapping area). A distance of 1 m from the bed was chosen as a standard sampling height generally used in coastal sediment transport investigations to represent near-bed conditions.

Standard traps were installed during the period June 22 to July 3, 1983 at all locations. An additional standard trap was installed 3 m from the other at station 2105, and the large diameter trap was installed 3 m from the standard trap at station 2104/2171 (nearest the active lakefilling operations where the greatest suspended particulate flux was anticipated).



STATION	DEPTH
1536	11 m
2110	10 m
2109	11 m
2108	11 m
2107	12 m
2106	17 m
2105	12 m
2104	16 m
2171	19 m
1419	8 m
2029	11 m.

FIGURE 3: Sediment Trap Locations

Following the initial deployment, a series of four diver retrievals and replacements was undertaken during the period July 1983 to June 1984 (Table 1). Each retrieval consisted of locating the sediment trap, capping it, removing it from the anchor post, installing a replacement, and bringing the full trap to the surface. All samples were submitted to the MOE Laboratory for determination of sediment dry weight and particle size, and analysis for sediment chemistry parameters. The station nearest the active lakefilling (station 2104) had to be relocated further offshore during the second retrieval (station 2171) since the first location was buried under the advancing lakefill.

4.2 Laboratory Methods

Following delivery of the collection tubes containing water and sediment to the MOE laboratory, samples were air dried and prepared for further analysis by removing large debris such as twigs and shells. After determination of dry weight, sub-samples were prepared for particle size analysis in a distilled water and dispersant solution (5% calgon). Particle size data for this survey were obtained by means of two Leeds and Northrup Microtrac Particle Size Analyzers. These instruments utilize the principle of low-angle forward scattering of a laser source projected through a stream of suspended sediment particles. Detection of the specific pattern is scattered light enables computation of the particle size distribution as a function of volume. Samples containing material larger than 4.5ϕ * (45 um) required use of both large and small analyzer, 0.0ϕ - 4.5ϕ [1000 um - 45 um) were then pooled with those from the small particle size analyzer, 4.5ϕ - 12.0ϕ (45.0 um - 0.24 um).

Although this analytical methodology is currently in a developmental phase at the MOE Laboratory, preliminary comparisons with sieving and settling methods have indicated that particle size distributions are generally comparable. The most obvious cause of differing results between the methods is the tendency for sieving and settling to underestimate the average diameter of non-spherical particles.

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* The ϕ scale is defined as $\phi = -\log_2 d$, where d = grain size diameter in mm.

TABLE 1: 1983/84 Toronto Waterfront Sediment Trap Installation and Retrieval Timetable

Station	Installed	Retrieval #1 Date	Days	Retrieval #2 Date	Days	Retrieval #3 Date	Days	Retrieval #3a Date	Days	Retrieval 4 Date	Days
1536	23 June/83	18 July/83	25	29 Aug/83	42	26 Oct/83	58	-	-	31 May/84	219
1419	29 June/83	21 July/83	22	31 Aug/83	41	26 Oct/83	56	-	-	1 June/84	220
2029	29 June/83	21 July/83	22	31 Aug/83	41	26 Oct/83	56	-	-	31 May/84	219
2104	3 July/83	20 July/83	17	Buried		-		-	-	-	-
2171	-	-		2 Sept/83*	New	2 Nov/83	61	-	-	6 June/84	218
2105	29 June/83	21 July/83	22	31 Aug/83	41	18 Oct/83	48	-	-	Not Found	
2106	23 June/83	20 July/83	27	31 Aug/83	42	18 Oct/83	48	-	-	Not Found	
2107	29 June/83	18 July/83	19	29 Aug/83*	New	18 Oct/83	50	-	-	6 June/84	233
2108	3 July/83	20 July/83	17	1 Sept/83	43	9 Nov/83*	New	13 Dec/83	34	Buried	
2109	3 July/83	20 July/83	17	1 Sept/83	43	9 Nov/83*	New	13 Dec/83	34	31 May/84	175
2110	22 June/83	18 July/83	26	30 Aug/83	43	11 Oct/83	42	-	-	Not Found**	

* Date replacement trap installed.
** Lost during dredging operation at Eastern Gap

Samples were analyzed for percentage loss on ignition (% LOI), total phosphorus (TP), total Kjeldahl nitrogen (TKN), arsenic (As) and trace metals (including Hg, Pb, Cd, Cu, Zn, Cr, Fe, Ni) according to MO standard procedures (Ontario Ministry of the Environment 1983). Hot acid digestion of air dried total samples was followed by ICP atomic emission spectroscopy for trace metals, and colorimetric analysis using an Auto Analyzer for TP and TKN.

5. RESULTS

5.1 Variability at Replicate Traps

The relative suspended particulate fluxes measured by the two standard traps at station 2105 have been listed in Table 2. These fluxes were in good agreement, although the variability increased with observed flux. A similar comparison of fluxes from the standard and oversize (i.e. diameter 20 cm, height 80 cm) traps at station 2104/2171 reveals much less consistency (Table 2). In this case, the variability was high for all retrievals, although once again there was an increase with successive retrievals. Observations at both stations 2105 and 2104/2171 indicated that the precision of flux estimates (in $g.m^{-2}\ d^{-1}$) decreased as the observed flux and length of collection period increased.

Comparison of grain size measurements (mean diameter and sorting in phi units) from the standard traps at station 2105, and standard and oversize traps at station 2104/2171 shows that relatively little variation occurred at each station with the exception of the second retrieval at station 2105. In general, however, results demonstrate that a similar range of particulate sizes was trapped at each location regardless of trap dimensions.

A comparison of selected chemistry results at these stations (Table 3) reveals good agreement for all available collections at the standard versus oversize trap station 2104/2171, demonstrating that variability in flux measurement had a negligible effect on sediment chemistry. The results from station 2105 were also generally in good agreement for the second and third retrievals, but exhibited large variability for the first retrieval (when a relatively small quantity of material was collected).

TABLE 2: Comparison of Physical Tests at Replicate Stations (2 standard traps at station 2105, 1 standard and 1 oversize trap at station 2104/71)

		REPLICATE STATIONS			
Parameter	Retrieval	2105 Std. A	2105 Std. B	2104/71 Standard	2104/71 Oversize
Flux ($g/m^2/d$)	1	5.1	5.5	1,078	929
	2	95.5	100.8	-	-
	3	171.9	195.8	341	737
	4	-	-	833	1,278
Mean D (ϕ) [Sorting]	1	-	-	5.2 [1.73]	5.2 [1.51]
	2	6.6 [1.78]	6.0 [2.10]	-	-
	3	6.5 [1.56]	6.6 [1.52]	5.9 [1.77]	6.0 [1.74]
	4	-	-	4.6 [2.07]	4.8 [2.14]

TABLE 3: Comparison of Selected Chemistry Results at Replicate Stations
(2 standard traps at station 2105, 1 standard and 1 oversize trap at station 2104/71)

		REPLICATE STATIONS			
Parameter	Retrieval	2105 Std. A	2105 Std. B	2104/71 Standard	2104/71 Oversize
%LOI	1	9.0	11.0	1.1	2.0
	2	3.5	3.6	-	-
	3	4.8	4.7	3.8	4.3
	4	-	-	2.3	2.7
Total P (mg/g)	1	1.3	1.3	0.8	0.9
	2	1.1	1.0	-	-
	3	1.2	1.0	1.2	1.2
	4	-	-	0.7	0.7
As (ug/g)	1	13.11	8.01	3.01	3.43
	2	3.95	3.64	-	-
	3	5.54	5.75	4.16	4.37
	4	-	-	3.21	2.76
Cd (ug/g)	1	2.90	1.40	0.53	0.48
	2	0.59	1.10	-	-
	3	0.73	0.70	0.63	0.68
	4	-	-	0.70	0.69
Hg (ug/g)	1	0.37	0.64	0.11	0.12
	2	0.13	0.11	-	-
	3	0.16	0.10	0.15	0.18
	4	-	-	0.08	0.07
Pb (ug/g)	1	99.0	81.0	92.0	100.0
	2	26.0	30.0	-	-
	3	37.5	34.7	53.5	61.5
	4	-	-	37.0	36.0
Zn (ug/g)	1	220	180	100	110
	2	92	92	-	-
	3	112	106	106	114
	4	-	-	58	57

5.2 Fluxes

The relative suspended particulate flux measurements at the various locations across the study area (Figure 4) revealed a general trend of order of magnitude differences between stations during each collection, and between collections at each station.
The widest range of fluxes between stations occurred during the first collection period when fluxes of less than 10.2 $g.m^{-2}d^{-1}$ were measured at stations 1536, 2029, 2105, 2106, 2107 and 2109, compared with 1,078 $g.m^{-2}d^{-1}$ in the immediate vicinity of the lakefilling at station 2104. This two order-of-magnitude range diminished with each collection period until by the fourth retrieval the maximum observed range varied from 200 $g.m^{-1}d^{-1}$ near the Island filtration plant intake (station 1536) to 1,026 $g.m^{-2}d^{-1}$ south of the Main STP discharge (station 1419).

Of the six stations for which a fourth retrieval was completed, the maximum range of fluxes through time was observed 700 m south of the lakefilling at station 2107. Observed fluxes increased from 2.6 $g.m^{-2}d^{-1}$ during the first collection period to 439 $g.m^{-1}d^{-1}$ during the fourth collection period. Excluding the lakefilling station 2104/2171 (which could not be compared quantitatively due to therelocation necessary after the burial of 2104), the minimum range of fluxes, from the first through fourth collections, was recorded near the Island filtration plant intake at station 1536 with values of 10.2 $g.m^{-1}d^{-1}$ and 200 $g.m^{-2}d^{-1}$ respectively.

5.3 Grain Size

Results of grain size analysis (Table 4) indicated relatively little variation in mean diameters (a) between stations in any one collection period, or (b) between the first three collection periods at any given station. During the first three collections mean diameters at all stations ranged from 5.2ϕ (27 um medium silt) nearest the lakefilling (station 2104) to 7.2ϕ (7 um: very fine silt) at the R.C. Harris filtration plant intake (station 2029), and sorting values (standard deviations) were less than 2ϕ at all stations except 2110. Grain sizes at each station varied by less than 1ϕ over the first three collections at all stations other than 2109 (1 km west of lakefilling).

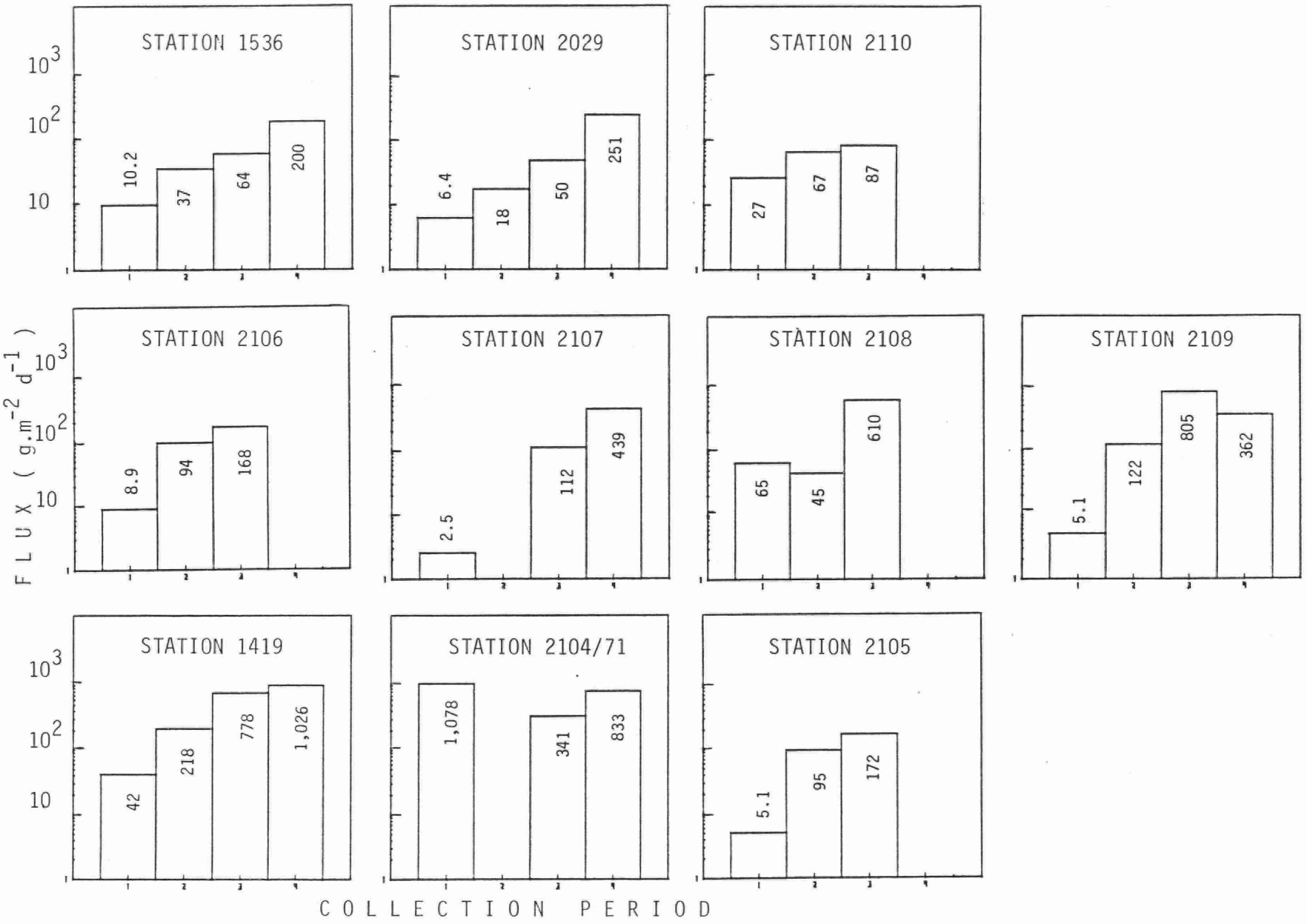


FIGURE 4: Suspended Particulate Fluxes

TABLE 4: Results of Grain Size Analysis on Toronto Waterfront Sediment Trap Samples 1983/84

		STATION LOCATIONS									
Parameter	Retrieval*	1536	1419	2029	2104/71	2105	2106	2107	2108	2109	2110
Mean Diameter (ø)	1	7.0	6.2	7.2	5.2	-	7.0	-	-	-	6.6
	2	6.7	6.3	7.2	-	6.6	7.0	-	7.0	6.9	5.9
	3	6.5	6.0	7.2	5.9	6.5	6.8	6.1	-	-	6.8
	3a	-	-	-	-	-	-	-	6.4	5.3	-
	4	5.7	5.4	4.3	4.6	-	-	4.9	-	6.3	-
Sorting (ø)	1	1.61	1.74	1.73	1.73	-	1.47	-	-	-	1.58
	2	1.61	1.70	1.80	-	1.78	1.61	-	1.40	1.52	2.30
	3	1.69	1.62	1.66	1.77	1.56	1.63	1.77	-	-	1.84
	3a	-	-	-	-	-	-	-	1.79	2.01	-
	4	2.28	1.94	2.32	2.07	-	-	2.16	-	2.10	-
% Silt/Clay (%< 63 um)	1	100	100	100	68	-	100	-	-	-	100
	2	100	89	100	-	94	100	-	100	100	71
	3	100	88	100	81	100	100	99	-	-	100
	3a	-	-	-	-	-	-	-	90	60	-
	4	73	73	36	52	-	-	58	-	85	-

* Retrieval: 1 (July 1983), 2 (August 1983), 3 (Oct./Nov. 1983), 3a (December 1983) 4(May/June 1984)

Material collected over the winter at all retrievable stations was distinctly coarser than for the first three collection periods (except for station 2109) with mean diameters from 4.3ϕ (51 um: coarse silt) at station 2029 to 5.7ϕ (19 um: medium silt) at station 1536. Sorting values during the winter collection were generally not as good as those observed during the first three collections, with standard deviations of greater than 2ϕ at five of the six available stations. Significant quantities of sand (i.e. >15%) were collected at all stations over the winter period.

5.4 Chemistry

If individual parameters are compared between stations, using the maximum range measured by the duplicate traps at station 2105 as the criterion for a significant difference, inspection of selected chemistry results (Table 5) reveals no significant differences among the ten stations over all available collection periods. This finding is supported by a Kruskal-Wallis one-way analysis of variance by ranks which indicates no significant ($P<0.05$) differences between stations for all parameters other than % LOI and As.

Examination of the chemistry results (Table 5) for temporal trends at each station indicates that, when present, differences occurred chiefly from the first to the second, and from the third to the fourth retrievals. Four stations (1536, 1419, 2029, and 2105) exhibited decreases in concentrations for most of the selected parameters. Stations 2108 and 2109 (to the west and southwest of the active lakefilling, respectively) were unusual in that not only were no decreases in parameter concentrations observed, but increases in Pb and Zn were detected at 2108 and an increase in %LOI was detected at 2109.

TABLE 5: Selected Chemistry Results from Toronto Waterfront Sediment Trap Samples

		STATION LOCATIONS									
Parameter	Retrieval*	1536	1419	2029	2104/71	2105	2106	2107	2108	2109	2110
%LOI	1	5.7	5.7	11.0	1.1	9.0	8.8	-	3.3	-	7.8
	2	4.5	3.5	7.1	-	3.5	6.2	-	4.4	4.4	5.9
	3	5.6	3.5	8.0	3.8	4.8	6.0	4.4	-	-	6.5
	3a	-	-	-	-	-	-	-	2.2	2.6	-
	4	5.1	1.6	3.2	2.3	-	-	3.0	-	5.2	-
Total P (mg/g)	1	1.1	3.2	1.30	0.80	1.3	1.2	0.9	0.8	0.6	1.4
	2	1.3	1.5	1.30	-	1.1	1.0	-	1.1	1.1	1.3
	3	1.5	1.2	1.30	1.20	1.2	1.3	1.5	-	-	1.3
	3a	-	-	-	-	-	-	-	1.0	1.1	-
	4	1.1	1.0	0.90	0.70	-	-	0.9	-	0.9	-
As (ug/g)	1	11.23	3.08	7.36	3.01	13.11	8.10	4.61	4.79	3.22	12.80
	2	5.81	3.64	5.64	-	3.95	5.43	-	6.39	5.64	6.50
	3	6.39	3.53	5.75	4.16	5.54	6.39	5.11	-	-	5.64
	3a	-	-	-	-	-	-	-	4.58	3.74	-
	4	6.35	3.03	4.48	3.21	-	-	4.12	-	5.46	-
Cd (ug/g)	1	1.6	2.80	2.10	0.53	2.90	1.60	-	0.82	-	1.80
	2	1.7	1.10	1.30	-	0.59	1.20	-	0.80	1.20	1.60
	3	1.8	0.60	1.02	0.63	0.73	0.70	0.78	-	-	2.02
	3a	-	-	-	-	-	-	-	0.72	0.77	-
	4	1.8	0.73	0.75	0.70	-	-	1.10	-	1.20	-
Hg (ug/g)	1	0.38	0.73	0.61	0.11	0.37	-	0.32	0.18	-	0.40
	2	0.30	0.17	0.18	-	0.13	0.15	-	0.23	0.19	0.30
	3	0.24	0.11	0.12	0.15	0.16	0.14	0.23	-	-	0.35
	3a	-	-	-	-	-	-	-	0.16	0.14	-
	4	0.14	0.05	0.07	0.08	-	-	0.12	-	0.19	-
Pb (ug/g)	1	85.0	94.0	80.0	92.0	99.0	74.0	-	53.0	-	110.0
	2	77.0	36.0	44.0	-	26.0	44.0	-	93.0	87.0	93.0
	3	73.7	31.0	47.2	53.5	37.5	42.5	61.0	-	-	131.5
	3a	-	-	-	-	-	-	-	58.0	59.0	-
	4	45.0	17.0	20.0	37.0	-	-	44.0	-	58.0	-
Zn (ug/g)	1	240	230	220	100	220	160	-	89	-	210
	2	160	110	150	-	92	130	-	140	140	170
	3	169	87	136	106	112	128	120	-	-	229
	3a	-	-	-	-	-	-	-	100	94	-
	4	110	48	58	58	-	-	87	-	100	-

* Retrieval: 1 (July 1983), 2 (Aug. 1983), 3 (Oct/Nov. 1983), 3a (Dec. 1983), 4 (May/June 1984)

The general tendency for significant chemistry differences between collection periods over all stations is supported by a Kruskal-Wallis one-way analysis of variance by ranks which indicates at least one significant ($P<0.05$) difference between collection periods for all parameters other than Cd. Although a two-way analysis of variance was not possible, inspection of the results (Table 5) suggests interaction between station effects and temporal effects.

All chemistry results from traps near the Main STP outfall (1419, 2105, 2105 duplicate), and at background stations (1536, 2029) were pooled separately and linear correlation matrices constructed for the two groups (Tables 6a, 6b). A relatively high degree of correlation among most metals is evident at both types of stations. The most notable exception is Fe which correlates significantly ($P<0.05$) with Cd, Cr, Cu, Hg, Pb, and Zn at background stations but not at stations near the Main STP outall. At background stations poor correlations exist between TP and metals and between % LOI and metals. For stations in the vicinity of the Main STP discharge, the opposite situation can be observed with significant correlations between TP and metals, and between % LOI and metals.

In general, concentrations of metals and nutrients did not correlate significantly with grain size indicators (i.e. % <64 um, % <16 um). Some significant ($P<0.05$) positive correlations were obtained with total P and % LOI near the Main STP and lakefilling stations (1419, 2104/71), as well as at background stations (1536, 2029). There were also significant correlations with Pb and Zn at background stations only.

6.0 DISCUSSION

6.1 Replicate Traps

Rosa (1985) reports variability among replicate traps to be between 5 and 10% which implies that variability increases with increasing flux. The same pattern was observed in results from station 2105. The increases in flux variability over successive collection periods observed at this station can be attributed to the accumulation of larger proportions of resuspended material under progressively more turbulent conditions.

TABLE 6a: Coefficients of Linear Correlation between Sediment Chemistry Data near the Main STP Discharge (stations 1419, 2105, 2105D)

	%LOI	TP	TKN	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	Fe
%LOI	1.00000											
TP	.17518	1.00000										
TKN	.88988	.54363	1.00000									
As	.78138	-.16621	.56348	1.00000								
Cd	.58073	.67719	.78913	.53238	1.00000							
Cr	.24029	.98913	.60088	-.09391	.73455	1.00000						
Cu	.64380	.85682	.86113	.28147	.82720	.89223	1.00000					
Hg	.74239	.75485	.94160	.30149	.75347	.78267	.94136	1.00000				
Ni	.96417	.23601	.85859	.73767	.57397	.30189	.69118	.72622	1.00000			
Pb	.83251	.61237	.93928	.64778	.91730	.66830	.89829	.88750	.98659	1.00000		
Zn	.78751	.67766	.91810	.58717	.91477	.73336	.93481	.88747	.81677	.98659	1.00000	
Fe	.70773	.08373	.48165	.59112	.26279	.14308	.46172	.40954	.77044	.53310	.54991	1.00000

n = 10, critical value = .62972 (P=0.05)

TABLE 6b: Coefficients of Linear Correlation between Sediment Chemistry Data at Background Stations (stations 1536, 2029)

	%LOI	TP	TKN	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	Fe
%LOI	1.00000											
TP	.46692	1.00000										
TKN	.87022	.37655	1.00000									
As	.20484	-.02082	.42140	1.00000								
Cd	.41778	.49340	.32507	.43864	1.00000							
Cr	.23370	.29711	.41435	.63324	.83094	1.00000						
Cu	.77079	.44486	.88445	.58833	.70067	.76455	1.00000					
Hg	.65676	.30683	.76581	.57116	.74841	.80134	.95486	1.00000				
Ni	.86703	.52732	.94509	.55523	.52743	.55819	.94135	.82261	1.00000			
Pb	.37417	.54429	-.52086	.69893	.78067	.87456	.80902	.80517	.72326	1.00000		
Zn	.56639	.45526	.75136	.81812	.66770	.79563	.90853	.84073	.88204	.91593	1.00000	
Fe	.71940	.38096	.76859	.61853	.78324	.81712	.94337	.88186	.86671	.77330	.86865	1.00000

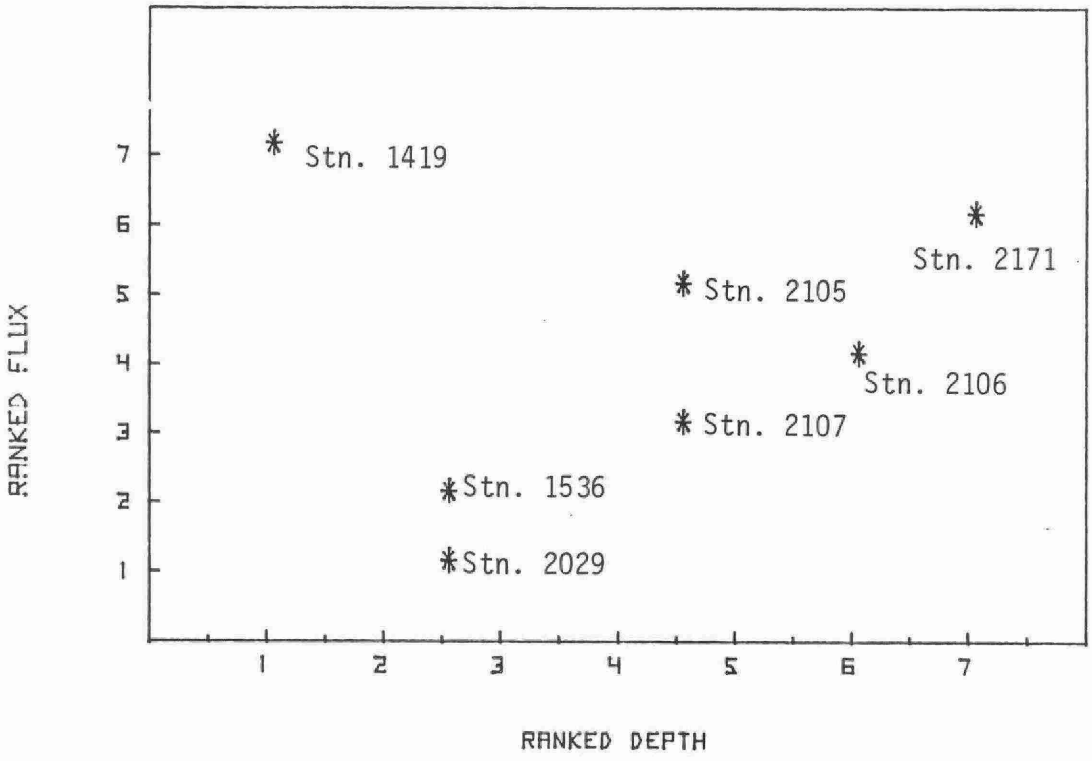
n = 8, critical value = .70477 (P = 0.05)

The high variability in chemistry data encountered during the first collection period may have resulted from the small sample volumes available for analysis (i.e. sample dry weights of less than 2 g were obtained at 6 stations) which would have increased the potential for interference during sample retrieval and preparation.

6.2 Fluxes

As stated earlier, in the energetic nearshore environment differences in observed particulate fluxes will result from a combination of differing energy environments and proximity to sources. The wide range of results obtained between unsheltered stations in each of the collection periods appears to result principally from proximity to sources. A convenient way to demonstrate this is to plot ranked flux results against ranked depth for a given collection period at unsheltered stations (i.e having equal exposure to wave energy). A typical example using third collection results (Figure 5) illustrates the absence of a relationship between increasing fluxes and decreasing depth. Such a relationship would be expected if local variation in shoaling wave energy near the bed was the primary cause of flux differences. Instead it is apparent that minimum fluxes were recorded furthest from potential sources (i.e. at stations 2029 and 1536) while maximum fluxes were observed nearest sources (i.e. at stations 1419 and 2171).

The seasonal flux increases observed at any one station, on the other hand, probably reflected the progressive increase in wave energy leading to increased shoreline erosion and resuspension of material deposited during the summer months. Although no attempt was made to quantify shoreline erosion in this study, previous investigations have identified bluff and shoreline erosion as being a major source of Toronto nearshore sediments (Lewis and Sly 1971, Rukavina 1976). An increase in flux of resuspended and shoreline material would be expected to both diminish the relative differences in fluxes between background and input stations, and to lower bulk sediment chemistry concentrations as a result of "dilution" by the relatively clean background material (Persaud et al. 1985). Both phenomena were observed during this study.



Station	Depth (m)	Flux ($g\ m^{-2}d^{-1}$)
1419	8	778
1536	11	64
2029	11	50
2105	12	172
2107	12	112
2106	17	168
2171	19	535

FIGURE 5: Ranked Flux versus Ranked Depth at Unsheltered Toronto Waterfront Sediment Trap Stations During the third Collection Period

In general, results showed fluxes in the vicinity of the lakefilling and Main STP to have been an order of magnitude greater than those recorded at background stations near the Toronto Island and R.C. Harris filtration plant intakes (Figure 1) with the greatest relative differences occurring during the summer months. An intermediate zone was detected in the vicinity of the East Headland. Assuming that proximity to source was the primary cause of these relative differences, there are several possible reasons for these observations. These could include: deposition (or settling below sediment trap levels) of suspended particulates occurred between source and background stations, reduction in suspended particulate concentrations occurred between source and background stations as a result of dispersion within longshore currents, and offshore transport of suspended particulates occurred due to a combination of slope and oscillatory currents under waves, or offshore undirectional currents.

Further investigation into local components of sediment transport would allow evaluation of the relative significance of each of these.

6.3 Grain Size

Grain size parameters did not provide a reliable means of distinguishing suspended particulate sources due to the general similarity in grain size distributions between stations. Data from the first three collections indicated that the predominant type of material in suspension 1 m from the bed was silt and clay at all locations, even near the R.C. Harris filtration plant intake (station 2029) where the bed consists of coarse sand (Persaud et al. 1985). This suggests that trapping efficiency was high (i.e. no major loss of fines from traps occurred) and that a wash load of fine suspended particulates from various sources moved through the system.

Coarse material was found to be associated with greater fluxes primarily during the fourth collection period. Significant proportions of sand (i.e. >25%) were collected at all unsheltered stations with the greatest contrast from previous collections occurring near the R.C. Harris filtration plant intake (station 2029). During the initial three collection periods no sand sized (i.e. >63 um) material accumulated at this station, whereas following the winter 64% of the material collected was sand. The increase in bed shear stress (and hence resuspension) and offshore transport associated with the winter wave climate (i.e. the establishment of a typical nearshore winter profile) was the most probable cause for this.

This evidence that sand sized material can be entrained and suspended 1 m from the bed in depths greater than 10 m during the winter supports observations that no net deposition of silt or clay occurs in the eastern waterfront from one year to the next even though temporary deposition may be observed near the East Headland during the summer.

The large sorting values (i.e. grain size standard deviations) observed during all four collection periods probably resulted from a combination of storm related fluxes of coarser material and relatively continuous fluxes of extremely fine material (i.e. fine silt and clay).

The tendency for poor correlations between concentrations or metals and nutrients with grain size indicators is not surprising given the limited size range of material collected at all stations prior to the winter period when predominantly fine grained material only was held in suspension 1m from the bed. Those significant grain size correlations which were observed could be attributed in large part to the increase in grain sizes accumulated during the winter collection.

6.4 Chemistry

The general lack of significant differences between stations for grain size, nutrients, and metals suggests that suspended particulates collected 1 m from the bed cannot be used to distinguish sources on the basis of single parameter comparisons. However, there is evidence that differences exist between background and input stations when linear correlations between parameters are compared.

The significant correlations between TP and metals, and between % LOI and metals observed in the vicinity of the Main STP discharge reflect physical or chemical associations which were not present at background stations (most probably with colloidal or particulate organic material). Differences can be attributed partly to differing sources and partly to different in-lake physical or chemical transformations of suspended particulates. Material collected at background stations would have undergone a greater degree of transport and mixing, and had a greater opportunity to equilibrate with the open lake environment than material collected in the vicinity of the Main STP discharge.

The lack of significant correlations between Fe and other metals in the vicinity of the Main STP outfall contrasts conspicously with the pattern observed at background stations. This finding indicates that particulate concentrations of Fe vary relatively independently from concentrations of most other metals near the STP outfall. The addition of iron salts during phosphorus removal at the plant may account for this. Investigation into the physical and chemical nature of suspended particulates at specific sources (i.e. rivers, STP's) is required in order to verify these preliminary findings.

The decline in concentrations of most parameters observed at unsheltered stations, particularly from the third to the fourth collections, can be linked to increases in fluxes of coarser material which will tend to have a diminished adsorptive capacity for contaminants. Previous investigations have shown the coarser material at the lake bed in this area to be relatively clean (Persaud et al. 1985). If chemistry results from the final retrieval are normalized according to grain size (i.e. percentage finer than 63 um) then many of the differences in concentrations between the third and fourth collections become negligible - particularly at the R.C. Harris filtration plant intake station (2029).

7. SUMMARY AND RECOMMENDATIONS

This study demonstrated the potential for useful application of sediment traps in an energetic nearshore zone environment. Major findings were as follows:

(1) The detection of large relative differences in suspended particulate fluxes (and associated fluxes of nutrients and metals) between traps situated near sources of suspended particulates and those at background stations, could be attributed to specific sources, once factors such as localized variation in resuspension of bed sediments or in trapping efficiency, were accounted for.

(2) Wave energy appeared to be the principal factor controlling seasonal variability in fluxes since they were greatest during the late fall and winter when wave energy would have been at a maximum and since no seasonal increases of the magnitude observed can be attributed to lakefilling operations or flows from the Main STP.

(3) Relative differences in fluxes between source stations (i.e near the Main STP discharge and lakefilling operation) and background stations (near the R.C. Harris and Toronto Island filtration plants) were greatest during the summer when the expected relative contribution from resuspension and shoreline erosion would have been at a minimum.

(4) Although grain size parameters, and concentrations of nutrients and metals could not be used individually to distinguish stations, the potential for discrimination on the basis of correlations between chemical parameters was identified.

Given these findings, the following general recommendations are offered for work in the Lake Ontario nearshore zone:

(1) Future investigations which seek to quantify differences in particulate flux and chemistry between unsheltered stations are most likely to succeed using results obtained during the summer months. Studies into sediment transport, however, should include results from the winter period.

(2) Sampling of suspended particulates from various sources (i.e. STP effluent streams, rivers) should be undertaken so that source classification by means of physical, chemical, and statistical tracers can be pursued.

(3) Future studies concerning the fate of trace contaminants in the aquatic environment should consider the use of sediment traps to investigate certain aspects of sediment transport (i.e. spatial variation in particulate fluxes) as well as the physical and chemical composition of suspended particulates near and removed from sources.

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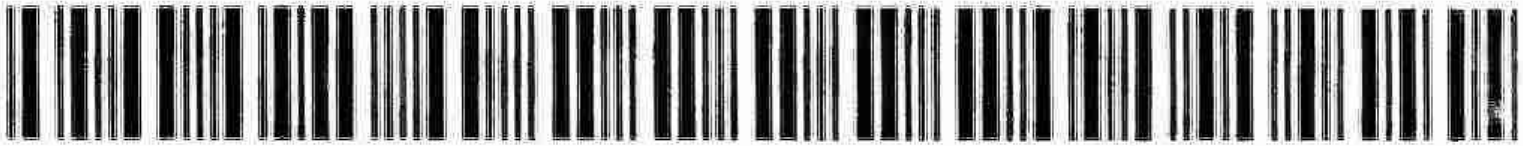
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